Climate change impacts on New Zealand’s biodiversity

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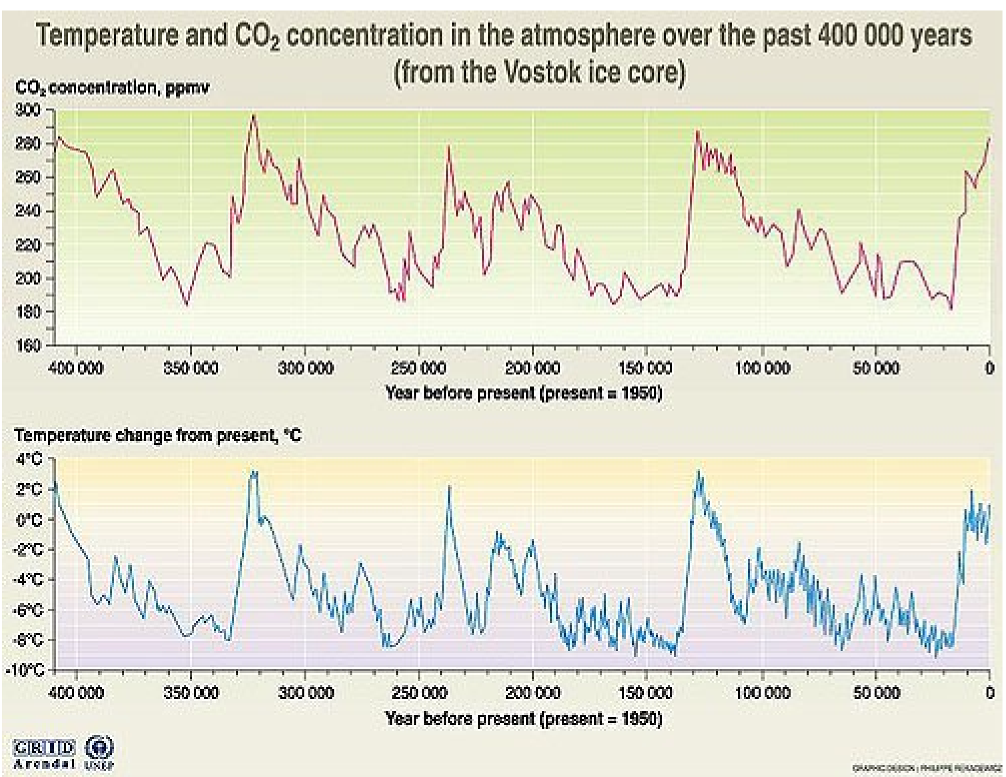
Prelude

New Zealand's biodiversity has always been profoundly shaped by climate change. Scientists who study the distant past tell a rich and dramatic story of enormous geological processes and climatic influences as one fragment of ancient Gondwana finally became the land people first called Aotearoa, then later – New Zealand (Stevens *et al* 1988).

Let us start this brief recap in relatively recent times – geologically speaking. About 2.4 million years ago polar ice built up and triggered a period of major global cooling that finally ended 10,000 years ago. During this Ice Age New Zealand was affected by many glacial episodes. Long cold glacial periods alternated with briefer periods of mild, even sub-tropical conditions when kauri forests probably extending as far south as Wellington. With the end of the Ice Age, New Zealand landscapes changed significantly. Fourteen thousand years ago when the ice finally started to retreat the landscapes over much of the North and South Islands were dominated by sparse grasslands and shrublands with small pockets of remnant beech and podocarp forest. Fast forward 2,000 years and the North Island shrubs and grasses had been almost entirely replaced by tall forests. The relatively rapid spread of forests from isolated pockets was probably due to seed dispersal by the rich bird life that then existed in New Zealand. Forests spread over the South Island more slowly, but by 9,500 years ago only central Otago remained free of any tall forest (Stevens *et al* 1988).

Links between temperature and CO_2 concentrations over past 400,000 years



Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3JUne), pp 429-436, 1999.

Ice cores taken from Antarctica tell a remarkable story of the temperature fluctuations during the past 400,000 years that covers the glacial episodes towards the end of the Ice Age and the current warming during the Holocene (last 10,000 years). The lower graph (previous page) shows that temperatures averaged 4^0 - 8^0 C colder than at present. The past 10,000 years (extreme right on the graph) has been the longest period of sustained warm temperatures during this entire 400,000-year period. The central point is the demonstration of the close correlation between temperature and carbon dioxide levels. During the coldest periods CO_2 levels dipped to less than 200 parts per million (ppm) compared with CO_2 highs of 280-300 ppm during the brief, warm intervals (upper graph).

Climate-mediated changes continued to affect our landscapes. A cooling trend that started 7,000 years ago led to an expansion of beech forests in both the North and South Islands. Beech forests continued spreading over the next 6,000 years, despite huge forest fires that devastated parts of both islands between 2,500 and 1,500 years ago. This unprecedented fire period may have been caused by increasing westerly winds, combined with high summer radiation. The densely forested New Zealand of 1,500 years ago with its uniquely rich birdlife had also faced and survived other violent changes. Earthquakes, sub-tropical cyclones, major volcanic events, heavy rain and erosion periodically damaged or obliterated forests on local or regional scales. The most dramatic 'recent' example was the Taupo Pumice eruption of around 130 AD. This eruption was one of the world's largest in the last 20,000 years. It destroyed thousands of square kilometers of forest, devastated the eastern North Island and deposited ash on the distant Chatham Islands. And yet, remarkably, within 300 years tall forest had reclaimed the flattened landscapes. Once again, the richness of the bird fauna most likely played a major role in spreading the seeds of both forest giants and understory plants (Stevens et al 1988).

While the ancient agents of change continue to influence New Zealand's biodiversity – earthquakes, erosion,[1] *sub-tropical cyclones, major rain events and droughts – they now do so over a landscape now vastly changed by human intervention.* Forty-four percent of the country's 27 million hectares that were previously forest and wetland systems are now pasture and arable land (MfE 2006). Indigenous forests have been reduced to 23% of land cover (6.3 million ha). In many regions forests now exist as scattered remnants, especially coastal forest ecosystems, which are about one percent of their original extent. The richness of native bird life that existed before human settlement has gone forever. Bird biomass was first reduced by habitat loss and hunting, and then decimated by introduced predators, mostly by mustelids and rodents, and also by possums. Introduced herbivores (especially possums, deer and goats) damage forest ecosystems and can significantly delay their regeneration processes. Exotic weeds can take advantage of disturbed sites faster than indigenous species, further disrupting ancient patterns of mortality and re-growth. *In short, the resilience of New Zealand's ancient forests and*

[1] Significant and severe erosion events have occurred in the past 2,000 years in mountain lands prior to humans arriving in New Zealand. These events were associated with heavy rainfalls, major floods and gales, regardless of vegetation cover (summarised by Grant 1989).

other ecosystems, and their ability to bounce back from environmental shocks, especially those imposed by rapid climate change, has been much reduced.

Finally, the carbon dioxide levels that are a major driver of global temperatures are no longer 300 ppm or less. Current CO_2 levels are at 380 ppm, possibly their highest level in the past 20 million years. This level has been reached rapidly by a 35% increase of CO_2 in the atmosphere since the late 1700s (WMO 2006). While CO_2 levels rose by less than 1% per year during the 1900s, the growth rate of CO_2 emissions has been 2.5% per year during 2000-2005. On the basis of this and other evidence climate scientists now suggest that global temperature increases by 2100 are more likely to approach 5.8^0C, which is a dangerously 'high end' of the IPCC 2001 projections (BBC 2006).

To the past agents of change that affected New Zealand's biodiversity we therefore need to overlay an extraordinary and ongoing rise in global temperatures, over a relatively short time, and the myriad consequences that are likely to flow from that phenomenon.

1. Introduction

1.1 Climate change and biodiversity: an emerging theme

Most of the focus on climate change in New Zealand has been influenced by overseas developments. These can been characterised as falling into three 'eras' (Huq and Toulmin 2006). The first era from the late 1980s to 2000, was marked by the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and the release of its first two assessment reports (1990, 1995). The major focus was on exploring the scientific evidence for climate change, establishing the United Nations Framework Convention on Climate Change (in 1992) and, under this convention, negotiating the Kyoto Protocol (1997). During this era, climate change was seen primarily as an environmental problem linked to global atmospheric changes. Solutions largely focused on mitigation to prevent impacts that were thought likely to happen only in the longer term. A useful and popular account of climate change impacts written for a New Zealand audience (McGlone et al 1990) had warned, however, that feedback loops could lead to much more rapid changes.

Sorting out the terms

What is the relationship between the terms *climate change*, *greenhouse gases* and *global warming*? First, the *greenhouse gases* (carbon dioxide, methane, nitrous oxide – in order of importance) can trap the sun's heat near the surface of the Earth. The concentrations of all of these gases are increasing in the atmosphere. The extra heat that these gases trap leads to *global warming*. The extent of this warming is now placing considerable pressure on the Earth's climate system which can lead to *climate change*. Note that weather and climate are quite separate concepts. Weather is what we experience every day. Climate is the sum of all weathers over a certain period, for a region or for the planet as a whole.

This summary is from the very readable "The Weather Makers" by Tim Flannery (2005) (Page 19)

The second era (2002-2005) was marked by the publication of the third assessment report by the IPCC (2001) which warned of unavoidable impacts of human-induced climate change in the near term, that is, within one to two decades. Hence, said the IPCC report, there would be a need to cope with impacts through 'adaptation measures'. Regionally different impacts were also highlighted. Poor countries, especially in Africa, would be more vulnerable and need international assistance to adapt. Perception of the problem thus became more complex. No longer 'just' an environmental problem, climate change now also threatened development goals. Solutions needed to go beyond mitigation to also include adaptation. The importance of this extra complexity was further strengthened in 2005 with the release of the global United Nations Millennium Ecosystem Assessment (MA). Climate change was shown to be a major driver negatively affecting all major biomes[2] on earth and therefore capable of reducing the capacity of ecosystems to provide the ecosystem services on which all development depends (MEA 2005). This was a message for developed as well as developing countries, although the extent to which it has influenced the policy world remains questionable. The economic importance of the 'environment' continued to remain outside the scope and awareness of most Ministers of Finance.

Despite a broadening of climate change issues to more rapid change and impacts on development, including impacts on agriculture and biodiversity, the major research and policy emphasis in New Zealand continued to focus on greenhouse gases and mitigation-related issues. Thus the New Zealand Biodiversity Strategy, released in 2000 after 4 years in development, has no objectives or actions concerning the possible impacts of climate change on biodiversity. In contrast, the Australian Biodiversity Strategy, published 4 years earlier in 1996, has an objective to minimise the potential impacts of climate change on biological diversity (Commonwealth of Australia 1996). This includes research on the primary and secondary effects of climate change on biodiversity and an action to *"Investigate the capacity of protected areas to sustain their biological diversity in the event of climate change and where appropriate ensure that altitudinal and latitudinal buffer zones or corridors exist to allow for the movement of organisms in the event of shifts in climatic zones."* (Objective 3.6, page 29) The 1995 Canadian Biodiversity Strategy also contains actions aimed at understanding climate change impacts on biodiversity (Minister of Supply and Services Canada 1995).

In late 2001, a pilot study on adaptation in the context of land management in Hawkes Bay was funded by the Ministry for the Environment (Kenny 2002). This work and its subsequent elaboration into efforts to engage farmers in responding effectively to climate change are well covered in a companion background paper commissioned by the Parliamentary Commissioner for the Environment (Kenny 2006a). Also in 2001 the first substantive effort to report on the linkages between climate change and indigenous biodiversity in New Zealand was published by Landcare Research as "advice to Government" (McGlone 2001). That report did not discuss possible linkages between climate change and marine ecosystems, but made recommendations on policy issues.

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[2] Biomes are the largest recognised unit of regional communities of plants and animals. Major biomes include tundra, tropical rain forests, desert, temperate grasslands, temperate forests, mountains.

The third era of climate change, according to Huq and Toulmin (2006), is only just underway. They anticipated it would start with the release of the Stern Review and the IPCC's fourth assessment report, due in 2007. They anticipated that both reports will "*…demonstrate that climate change is already happening*" and will shift the focus from being an environment and development issue to one of global justice – recognising that poor people and poor nations are suffering the most adverse consequences of the excesses of the rich. The Stern Review, released in November 2006, does indeed conclude with a sense of urgency:

> "*The scientific evidence is now overwhelming: climate change is a serious global threat, and it demands an urgent global response. … Climate change will affect the basic elements of life for people around the world – access to water, food production, health, and the environment.*" (Stern 2006)

Stern, a former Chief Economist of the World Bank and head of the UK Government Economic Service, argues that the cost of prompt global action can be limited to around 1% of global GDP each year, whereas inaction will lead to losses equivalent to losing at least 5% of global GDP each year, possibly rising to 20% of GDP or more. The Times newspaper responded by suggesting the Review made the "invaluable contribution" in that "*…it recasts environmentalism as economics*". Whether Stern's arguments will lead to an effective dialogue between economists and environmentalists remains to be seen, but the economic, political and social risks from climate change have been moved to centre stage.

What emerges from these various reports and perspectives is recognition that climate change issues will not be resolved by more linear thinking along the lines of: science → policy → mitigation → adaptation. There are strong feedback loops between all of these elements as well as uncertainties, conflicting value sets, multiple players and geo-political complications. From a scientific perspective, managing climate change has been characterised as a "wicked issue" whose complexities, competing knowledge systems and contentious positions may make it an intractable problem (Lorenzoni *et al* 2006). Lorenzoni *et al* propose that 'boundary organisations' might play an important role in developing management responses to climate change problems.[3]

In the final analysis, climate change is a social problem, in its causes and solutions, a point explored more thoroughly by Kenny (2006a) in its New Zealand agricultural context.

1.2 Purpose and structure of this paper

The policy and research focus on climate change in New Zealand has been dominated by mitigation issues centered on reducing greenhouse gas emissions and, more recently, on some consideration of adaptation responses. There has been little attention paid to how our indigenous biodiversity is likely to be affected by climate change. The MA reports,

[3] 'Boundary organisations' and their role in assisting the resolution of complex problems involving science, environmental policy and management were considered in detail in an earlier PCE report (PCE 2004a).

by way of contrast, have shown that at the global level climate change is already adversely affecting the major ecosystems upon which countries depend for ecosystem services, such as fresh water, forests and soils (MEA 2005). What are the effects on New Zealand and how might they change not only the future of natural systems, but also the future well-being of an economy that relies heavily on biological systems?

For any sustainable development initiatives to succeed it is important therefore to develop intelligent policy responses and actions in response to the effects of climate change on biodiversity. This background paper will focus on our indigenous biodiversity while recognising that a quite separate and important topic is the implications for introduced biodiversity (Kenny 2006a). I also comment on the need for policy work and a re-think of how climate change will affect the agencies that are responsible for managing biodiversity.

Section 2 briefly summarises the current understanding of what climate changes are likely for New Zealand. This will set the scene for examining the likely pressures and consequences for New Zealand’s indigenous biodiversity. The need to change policy mindsets and look at the very different timescales for responses from a management perspective is covered in Section 3. Sections 4 and 5 summarise what is known of the impacts of climate change on different ecosystems and how, in a broader context, some ecological processes are likely to be more affected than others. What we don’t know, but will need to explore more thoroughly about the linkages between climate change and effects on biodiversity, is raised in Section 6. This will need further elaboration and analysis elsewhere as it challenges the current framework for thinking and responding to threats to conservation. What we need is a futures-focused framework that can take into consideration long-term changes while responding to short-term needs.

2. New Zealand climate futures – current predictions

There has been a warming trend in New Zealand since the 1940s and mean temperatures have increased by 0.7^0C between 1900 and the 1990 (Folland and Salinger 1995). Temperatures will continue to rise, although by how much remains conjecture. At the global level, climate models predict warming by 2100 of between 1.4 and 5.8^0 C depending on which scenario is used. These estimates will be further refined by the IPCC in its next assessment report, due in 2007. Given the increasingly strong evidence for climate changes it is possible that these estimates will be revised upwards.

New Zealand’s marine environment and its long, relatively thin shape reduce the likely rise in mean temperatures. Current projections give a New Zealand-average warming of $0.2\text{-}1.3^0$ C by the 2030s and $0.5\text{-}3.5^0$ C by the 2080s (MfE 2004). Warming will be strongest in winter, with more warming in the northern and eastern regions. Strong winter warming will reduce the number of frost days, possibly by half in the South Island. There will also be more high temperature episodes. Days with temperatures over 25^0 C in the north and east of the North Island may increase by 30-50%. These significant shifts

towards fewer frost days and more very hot days are a direct consequence of small changes in average temperatures.

In a similar manner, average shifts in rainfall patterns are predicted, accompanied by more frequent associated events, i.e. more floods and droughts. Changes in mean rainfall will vary substantially between regions. Predicted increases in the mean westerly windflows across New Zealand would increase rainfall in western regions (Taranaki, Manawatu-Wanganui, West Coast, Otago and Southland). With more rainfall in the west, there is likely to be less rain in eastern regions (Hawke's Bay, Gisborne, eastern Canterbury, and eastern Marlborough) (MfE 2004). There are likely to be two major consequences of these shifts. The first is heavier and more frequent extreme rainfalls in the wetter western regions – such as experienced in the Manawatu floods of February 2004. The second is the impact of the combination of higher temperatures and reduced rainfall for the future risks of drought in eastern regions. A report by Mullan *et al* (2005) on drought risks investigated four scenarios using the mid-range global temperature increases. By the 2080s, in their 'low-medium' scenario severe droughts (defined as the current one-in-twenty year drought) were projected to occur at least twice as often as at present in parts of Northland, Bay of Plenty, Hawke's Bay, Wairarapa, Marlborough, Canterbury and Otago. Under the 'medium-high' scenario parts of these same eastern regions would experience the current one-in-twenty year drought (on average) 4 to 8 times more frequently, i.e. between once every 5 years to once every 2.5 years by the 2080s. Drought may extend into spring and autumn months.

As well as the rise in westerly windflows current knowledge suggests that ex-tropical cyclones might be slightly less likely to reach New Zealand, but if they do affect New Zealand their impact may be greater than usual (MfE 2004). Such cyclones are generally confined to northern and eastern regions of the North Island. Tropical cyclones are affected by El Niño conditions which may have more influence in the tropical Pacific over the next 50 years. Sea levels will rise; the only uncertainty is by how much. Current estimate for New Zealand are for increases of between 9 and 88 cm before 2100. Since these estimates were made, however, the Greenland glaciers and Antarctic ice shelves have been melting at much faster than earlier predicted rates. Increased westerlies would lead to an increased frequency of heavy swells for coastal regions exposed to the prevailing winds. This effect would be compounded by higher sea levels.

These broad patterns of predicted change may well need further revision in 2007 after the next IPCC report, but they forecast significant climate changes, primarily with respect to rainfall – more frequent droughts in the east of the country and increased floods and rainfall in the west, coupled with temperature rises that would bring fewer frosts and more very hot days. These changes will be superimposed on natural variability which is, from time to time, already responsible for major impacts on the landscape and biodiversity.

It may be that an increase in the frequency of extreme events (heavy rainfall, drought, very high temperatures, storm surges, wind storms) will be the major climatic influences for New Zealand's biodiversity arising out of climate change. The other summary point is

that climate changes will not be uniform throughout the country: the present rainfall gradient will steepen; hot days will increase markedly in the north but not in the south. Policy and management responses will need to pay particular attention to the consequences of increased extreme events, and less to the gradual rises in average temperature or rainfall.

3. Timescales for changes in biodiversity

McGlone (2001) discusses climate change effects on two timescales and those effects are summarised below (Sections 3.1, 3.2). His 'long' timescale is around 120,000 years which is the average length of a glacial-interglacial cycle. A 'short-term' scale is about 500 years, reflecting the lifespan of some forest canopy species. While neither timeframe is reflected in current policies or policy considerations, McGlone rightly argues that these timeframes should be considered to keep open the future options for the evolution of our indigenous biodiversity. I return to this point in Section 3.3.

3.1 Possible long-term effects of climate change

The earlier graph showed the recent pattern of short interglacial periods between long periods of colder conditions. Levels of CO_2 are likely to remain high for a long period of time which is likely to extend the current warm (interglacial) conditions for at least 50,000 years, or four times longer than average. The majority of New Zealand's plants and animals evolved during the relatively cooler periods of the last 2.5 million years. Adjustment and adaptation will be forced on species faced with relatively rapid rises of temperatures of up to 3.5 to 8^0 C. Loss, or a major transformation of some habitats will occur. Current alpine communities and ecosystems will be particularly threatened. These cold-adapted communities are likely to eventually 'run out of room'. Lowland North Island areas may be transformed from temperate to sub-tropical climates as temperatures rise to the warmest experienced in the past 3 million years. Another long-term consequence concerns soil development. Soils in New Zealand have been regularly rejuvenated by erosion and wind-blown loessic dust during long glacial periods. With a major extension of time until the next glacial period a slow loss of mineral nutrients through leaching of the upper soil layers is likely. How this will play out in terms of the complex relationships within soil ecosystems remains an important research topic with considerable implications for land use practices (Wardle *et al* 1998).

The third long-term consequence of an extended warm period will be the disruption for cool- and warm-adapted species of the more usual cycles of alternating expansions and contractions. The cold-adapted species will lose out over time in a permanently warm climate and may only be able to survive in a decreasing number of places. As a consequence of these long-term changes the potential for indigenous plants and animals to evolve will be radically altered. McGlone (2001) proposes that while current management of biodiversity is "appropriately devoted" to responding to threats from predators, weeds and habitat destruction, "…*these activities should take place in the*

context of a broader strategy that seeks to maintain evolutionary processes over the longer term."

What might this mean for public management agencies and private landowners facing issues of conserving biodiversity on a timescale usually measured in terms of the current financial year, not the next interglacial period? The answer, in short, is to keep as many options open as possible for natural selection and evolution to respond to future unpredictable changes. In practice this means maintaining, in McGlone's words, "…a substantial indigenous presence throughout the range of managed *and disturbed* landscapes [to] help ensure this evolutionary potential." I have emphasised 'disturbed landscapes' to draw attention to the poorly recognised fact that a disproportionately large percentage of many threatened plants and animals, habitats and ecosystems only occur in New Zealand's much-reduced, highly modified environments (Walker *et al* 2006; de Lange *et al* 2004). These are mostly located in our coastal, lowland and montane environments. These threatened environments also have low levels of legal protection despite a range of voluntary protection mechanisms and provisions of the Resource Management Act (Walker *et al* 2006). Current trends of habitat loss, primarily on private land, mean that many species face more immediate threats well before any long-term pressures for adaptive changes

This latest research finding contrasts with the prevailing view that the important candidates for biodiversity protection are only pristine environments. From both short- and long-term perspectives, it is now clear that greater protection of depleted and highly modified habitats is essential to prevent the extinction of many indigenous species (Green and Clarkson 2005).

3.2 Possible short-term effects of climate change

McGlone (2001) reports on the limited evidence available for responses by indigenous biodiversity to climate change over the last century. Any shifts in the treeline appear to have been much less than might have been expected from the amount of climatic warming that has occurred (Cullen *et al* 2001). Certainly there has been no recent upward movement of the beech (*Nothofagus)* tree-line comparable to movements in many Northern Hemisphere tree lines. Evidence of changes in the ranges of individual tree species is largely anecdotal. Some northern species have expanded in areas where they have been transplanted, e.g. pohutukawa (*Metrosideros excelsa*) and karaka (*Corynocarpus laevigatus*) in the Wellington region.

There is evidence, however, that species known for mast-seeding (notably beech species and snowgrasses) show links to climate (Webb and Kelly 1993) with more frequent mass seeding following warmer than normal summers. Warmer than normal summers have also been related to the seeding cycles of snowgrass species (McKone *et al* 1998).

3.3 Response options: the problems of scale

How best to keep options open so that New Zealand biota might respond and adapt to short- or long-term climatic changes? This raises challenges for ecological theory and conservation management at a number of scales, including the social (Cumming *et al* 2006). An important question is the appropriate spatial scale over which actions have to be taken if they are to be ecologically effective. One response to the loss of forests in New Zealand has been to protect scattered areas of forest on private land. But are small remnant patches of native bush capable of playing a useful ecological role beyond being scenically ornamental? The fragmentation of habitats has long been considered a major threat to biodiversity, but Fahrig (2003) suggests this might be more strongly related to actual habitat loss than fragmentation *per se*. There are scale questions involved (patch vs landscape scales) that need more research to test and clarify the most effective responses.

A common response worldwide to habitat fragmentation has been to create 'landscape or wildlife corridors'. Corridors link natural areas, allowing plants and animals to move between them, thus reducing localized extinctions and, in theory, allowing longer term shifts of whole communities over time.[4] Despite a voluminous scientific literature on corridors, experimental evidence on their effectiveness at preserving biodiversity at large scales has been scanty. Recent results of a large scale experiment in South Carolina, however, has shown benefits of corridors (Damschen *et al* 2006). Habitat patches connected by corridors retained more native plant species than did isolated patches. Earlier papers from this 6-year experiment had shown the benefits of corridors with higher movements along them by species as diverse as butterflies, small mammals and bird-dispersed plants (Hadded et al 2003). A wider appreciation of working at landscape-scale patterns (Turner 2006) and new analytical tools (Chetkiewicz *et al* 2006) are strengthening the roles and applications of wildlife corridors.

Corridors have also been proposed as an adaptive response to climate change by creating sufficient 'ecological space' for plant and animal communities to shift to new zones where they can survive under changed climatic conditions. A contrary view on the potential value of corridors is expressed by McGlone (2001). McGlone addresses corridors as a response to climate change and questions their value in the New Zealand context, arguing that plant populations in New Zealand tend to contract and expand within regions. This is a different issue from the value of wildlife corridors as a mechanism for the movement of plants and animals between fragmented habitats. The research testing for the value of corridors for a response to climate change in New Zealand would appear to be lacking despite its potential long-term importance.

[4] One proposed wildlife corridor at a regional scale would run from Yellowstone National Park to the Yukon Territory, a distance of almost 3,000 km.

3.4 Timescales: a management challenge

In a New Zealand context the predictions of long-term climate change pose two quite different challenges for biodiversity conservation, but a point of connection is the overall relevance of management at the ecosystem scale (Park 2000). The most common situation on private land, as discussed above, is the problem of habitat loss and fragmentation. For landowners and regional councils the science, establishment and management of wildlife corridors may well require greater consideration than they receive at present, quite apart from the immediate problems of ongoing losses of modified, threatened ecosystems and their associated species.

For agencies such as the Department of Conservation (DOC) with its responsibilities for managing large-scale areas of indigenous ecosystems the challenges are different. How might long-term changes affect our major ecosystems and would agencies be able to respond appropriately? There may be pointers from a study that looked at climate change implications for Canada's national park system (Scott *et al* 2002). They examined the extent to which biomes in Canada's national parks would be vulnerable under a range of climate change scenarios. The modelling results suggested possible major changes for biome types in more than half of the national parks. It concluded that climate change represented "*an unprecedented challenge to Parks Canada*". The study also identified a range of potential vulnerabilities in existing policy and planning frameworks, including overall planning, as well as fire and exotic species management plans. Since equivalent modelling for New Zealand's national park and conservation parks system has not been done we do not yet know if DOC would face management challenges of a similar nature and scale.

Hannah *et al* (2002) argued that conservation strategies have paid little attention to climate change. They recommended stronger collaboration across disciples, including biogeography and palaeoecology, at regional scales to help management of protected areas. Welch (2005) outlined a useful set of principles and actions, over various time scales, to guide the response of protected area managers to climate change. He emphasised the importance for agencies to address climate change in management plans, to use adaptive management techniques and to adopt risk management approaches. A review of Australian research on predicted climate change impacts noted that significant impacts were expected on most vegetation types that have been modeled to date (Hughes 2003). "*The bioclimates of some species of plants and vertebrates are predicted to disappear entirely with as little as 0.5-1.0^{0}C of warming*." Like New Zealand, Australia lacks the long-term datasets that would allow the early detection of climate-related changes. Hughes (2003) documented a number of shifts in species distributions in Australia that "*…offer circumstantial evidence that temperature and rainfall shifts are already affecting geographical ranges*."

4. Short-term impacts on ecosystems

The following sections summarise current understanding of climate change impacts on ecosystems that are, with varying degrees of probability, likely to affect New Zealand species and ecosystems during the coming decades.

4.1 Marine and coastal

New Zealand's climate, both terrestrial and marine, is strongly influenced by a dynamic system that scientists refer to as the 'Southern Oscillation' – an atmospheric circulation system generated in the Pacific Ocean. McGlone *et al* (1990) provided a popular version of how it works. Our climate is particularly affected by the two extreme conditions of the Southern Oscillation – 'El Niño (warm phase) and 'La Niña' (cold phase). The Southern Oscillation has a cycle length of 2-7 years and the two extreme conditions, when they occur, can each last for 6-18 months. Each of the extreme conditions brings its own characteristic patterns of changed wind patterns and temperatures that drive significant switches in patterns of rainfall and drought, although droughts can occur in both phases. For example, the summer of 1982-83 was dominated by the most pronounced El Niño in a century. Western and southern regions suffered under bleak and cold weather while the east of the North Island baked under a major drought (McGlone *et al* 1990). Just 6 years later the other extreme, a La Niña event, brought reverse conditions. A summer of heavy rains drenched the north of the North Islands while dry, hot conditions in the west and south of the country brought another drought for the farmers.

The reason for including this brief reference of the Southern Oscillation is its link to climate change effects. Climate change conditions of more intense westerly windflows are likely to intensify the fluctuations of El Niño and the Southern Oscillation. If this happens the consequences will be felt in both marine and terrestrial environments.

New Zealand's Fourth National Communication (MfE 2006) notes that ocean surfaces have warmed by almost 1^0C over the past century. Changes of this magnitude can affect many fish species with respect to the survival of juveniles, predator-prey relationships, feeding regions or changing preferred spawning areas. The hoki fishery, which has recently declined significantly, has shown some negative correlation with warming conditions, but separating these impacts from fishing pressure is difficult. In contrast, snapper and gemfish appear to have improved recruitment and faster growth rates in warmer conditions. Studies of how climate change will specifically affect New Zealand's marine environment appear to be very limited, aside from work on commercially-important species.

International research has shown large-scale linkages between climate change and marine systems. For example, large-scale changes in the relationships between phytoplankton, zooplankton and salmon have been linked to sea surface temperature changes in the North Atlantic (Beaugrand and Reid 2003). Antarctic marine species are, with few exceptions, more sensitive to temperature variations than are marine groups elsewhere to

the extent that a 2^0C rise in sea temperature could cause some species to crash (Peck *et al* 2004). Other research indicates, however, that changes in ocean chemistry could be more important than changes in temperature for the survival of many marine organisms (Harley *et al* 2006). About 30% of current CO_2 emissions are absorbed by the oceans, a process that is expected to substantially decrease the pH of oceans, thus making them more acidic, over the next few centuries. The expected pH changes are higher than any pH changes inferred from the fossil record over the past 200-300 million years (Feely *et al* 2004). These changes will disrupt the processes that make key minerals available for calcifying organisms, such as the invertebrates and algae that build coral reefs. Small decreases in pH levels have been shown in laboratory studies to lower the metabolic rate and growth in mussels (Michaelidis *et al* 2005) which may have relevance for New Zealand's mussel aquaculture industry.

Using long-term data sets (which we lack for New Zealand) a UK project (the MarClim Project) has been able to demonstrate that real, measurable and growing impacts of climate-induced changes have already occurred throughout marine ecosystems (Laffoley et al 2006). Using six decades of data from 50 temperature-sensitive seashore species, the project showed effects on large as well as small species that were detectable over large scales (hundreds of km). While equivalent studies are not available for this region a precautionary approach would suggest that these findings have relevance for New Zealand's efforts to establish a representative system of marine reserves. In a report from the MarClim Project to decision makers and policy advisors, Laffoley *et al* (2006) made recommendations that may well be useful for New Zealand policy counter-parts:

- "The action directed at establishing individual marine and coastal protected areas must recognise the need to work with dynamic boundaries, as a consequence of marine climate change impacts, as well as the natural dynamics of the environment;

- The actions directed at meeting requirements to establish networks of marine and coastal protected areas should build in sufficient replication of sites and geographical coverage to ensure that the sum total effect has resilience in the face of marine climate change impacts; and

- A flexible approach should be taken to the incorporation of recovery and conservation areas into broader marine management mechanisms, such as spatial planning, to avid 'over planning'. Care should be taken to avoid decisions that make it more difficult to cope with future climate."

While the effects of climate change within New Zealand's marine environments may be little studied and poorly understood at present, there is more certainty regarding potential coastal effects. Rising sea levels and warmer sea-surface temperatures will be additional stresses on estuarine systems that are already stressed by human activities, such as excessive sediment loads and pollution. In some natural coastal communities sea level rise may be matched by the rate at which new inland areas of marshland habitats and estuaries can be formed. In other regions where the built environment extends to the

coastal edge this natural re-adjustment is not likely to be allowed to happen. Impacts may well vary substantially between regions. Western coastlines where erosion is already a problem face the additional combined threats of rising sea levels and greater frequency of storm surges. Increased droughts in eastern regions will reduce river flows and make estuaries saltier which may affect some estuarine vegetation and animal species. Mangroves are a warm temperature species and are spreading and moving south. While they play important ecological roles, and are an effective coastal buffer against storm events (and tsunamis) mangroves are often seen in negative terms by local communities. Warmer sea and estuary temperatures will favour more frequent blooms of toxic algae as well as the spread of invasive species such as *Undaria* seaweed in estuaries and harbours. Other exotic marine species in already in ports, harbours and around the coasts may find warmer conditions more favourable for their growth.

Overall, the effects of climate change on coastal environments will be negative and will vary from region to region. They will come as additional stresses to those imposed by human activities, polluting runoffs, large sediment loads, fishing pressures and coastal developments.

4.2 Freshwater and wetlands

It seems likely that indigenous fish species will be little affected directly by rising temperatures given their wide distribution in diverse habitats and genetic diversity (Glova 1990). Modelling work by Glova showed that under pressure from warming water temperatures brown trout and rainbow trout could shift their distribution southwards. Since trout are major predators and competitors of indigenous fish, such a shift would benefit native fish species. McDowell (1992) concluded that direct impacts of climate change are likely to be slight on indigenous New Zealand fish species.

The most important climate effects on freshwater systems and wetlands are likely to arise from secondary effects of rising temperatures and changed rainfall patterns. An analysis of climate change impacts in the Bay of Plenty (Kenny 2006b) notes that the current eutrophication of the Rotorua Lakes is accompanied by algal blooms. These blooms are triggered by extended periods of hot, still weather which will increase in frequency thus stimulating further eutrophication and algal blooms. These effects are likely to occur in other regions where freshwater quality is low, which certainly includes other agricultural regions. In the Bay of Plenty and regions where less rainfall and increased droughts are predicted, declining river and lake levels are also likely. There may be a significant impact on the aquatic macrophytes,[5] especially the deeper native communities (Kenny 2006b). When algal production increases, light does not penetrate so deeply into the water which reduces the bottom limit at which macrophytes can establish. The water conditions of eutrophic lakes and rivers also enable introduced pest fish and aquatic weeds to thrive at the expense of indigenous plants and animal species. Hence climate change is likely to promote conditions that favour the expansion of invasive species and

[5] Macrophytes are large, rooted aquatic plants.

the destruction of native plant communities, hence further stressing freshwater ecosystems.

These same impacts will apply to wetland habitats which are already under greater threats from human activities, most of which are related to agricultural intensification and land use changes (PCE 2004b; Green and Clarkson 2005). Since many agricultural regions are likely to face drier conditions and more frequent droughts there will be increased demands for extraction of river and groundwater for irrigation. These demands will further stress wetlands and aquatic ecosystems that rely on these water sources. Hence native fish species, while coping with a range of temperatures, could be at risk from disruptions caused by droughts leading to low water flows and the drying of streams and rivers. Low water flows will be exacerbated by water extraction for irrigation. These conditions will favour a rise in pests and aquatic weeds which will be further stresses on native species.

4.3 Forests

This section will cover direct effects of climate change on forests and forest species. There are other potential impacts of climate on forests that are covered in Section 5. Hall and McGlone (2001) using forest simulation modelling and pollen data predicted that climate change would have significant effects on the composition of New Zealand forests. It could be instructive to undertake further modelling work on New Zealand's forests using a range of temperature and precipitation scenarios as was done for Canada's national park system (Scott *et al* 2002; refer Section 3.3).

McGlone (2001) discussed various factors that make it difficult to predict how climate change might affect distributional changes of individual tree species. These include the variety of diversity patterns within New Zealand, individual plant attributes, role of soils, and the wide variety of factors (e.g. predators, herbivores, parasites) that may limit the habitats a species actually ends up occupying. It does seem likely, however, that many of the warmth-loving plants and animals now found in Northland will find new habitats becoming available further south. While this seems likely for tawa (*Beilschmiedia tawa*) (Leathwick *et al* 1996), it may not be the case for kauri (*Agathis australis*) given its particular soil requirements (Mitchell and Williams 1996). Such modelling approaches look at correlations between various climate factors and current distributions. How climate change actually affects forest species and ecosystems may be determined more by a host of other factors quite apart from the specific adaptive responses of individual species (Jump and Penuelas 2005).

For example, invertebrates, unlike vertebrates, are highly climate sensitive and show significant positive responses to warmer temperatures. For these reasons there will be major responses to warmer conditions by invertebrates, notably by insects, but when, and by which species will be highly unpredictable. One such dramatic 'response' has been shown by the mountain pine beetle in British Columbia, Canada. The mountain pine beetle (*Dendroctonus ponderosae*) is normally an insignificant component in the forests

of lodgepole pine and other conifers that cover much of British Columbia. However, a decade of successive warm winters, coupled with an abundance of old lodgepole pines (from years of successful battles against forest fires), have removed the usual constraints of patchy food supply and severe winter cold. Average winter temperatures in British Columbia have risen by more than 4^0C in the last century. The result has been an explosive growth of pine beetle populations that affected 8.7 million hectares of British Columbia's forests by 2005, an area equivalent to one-third of New Zealand's total land area. The loss of trees is now estimated at double the annual cut by all Canadian logging operations (Washington Post 2006). Without the return of early cold snaps, or long spells of killing cold (below minus 10^0C), the mountain pine beetle might extend its impacts past the Canadian Rockies and into the northern boreal forests.

Unpredictable consequences of climate change for New Zealand's forest ecosystems from pest and disease outbreaks and extreme climatic events should be expected. Damaging outbreaks of *Platypus* beetle have, in the past, killed mature beech trees and changed forest structure (Wardle 1984). Such outbreaks have been linked to warm temperatures and drought conditions that promote excessive honeydew production, which in turn promotes the *Platypus* outbreaks. Although beech species have experienced *Platypus* attacks over millennia, if climate change provides the conditions for more severe and more frequent outbreaks, then the outcomes could be more damaging over the long term. If pest outbreaks are coupled with more frequent droughts in the rainshadows of the eastern regions, the combined stresses could reduce the chances of forest restoration. Some of these areas may become too dry to support indigenous forest (McGlone 2001).

Future extremes of rainfall and temperature will almost certainly lie outside the current range (McGlone 2001), as discussed in Section 2. The increased frequency of extreme events that is forecast (MfE 2004) is likely to affect New Zealand's forests given that there are already numerous examples of disturbance determining forest structure. Heavy rainfall and storms can lead to major erosion events which can have long-lasting effects on waterways, freshwater species, and sediment loads. Excessive sediment, in turn, can have negative impacts on estuaries and coastal marine communities which could add to other stresses. At the other extreme, prolonged drought has been linked to changes in forest structures (Grant 1984).

4.4 Alpine zones

Predictions are for decreased snow cover, a rise in the snow line and shorter snow seasons (MfE 2004). McGlone (2001) noted that about 40% of the plant species regularly occurring in the alpine zone are also found below treeline (Mark and Adams 1995) and suggested that it is not yet clear if warming has directly affected, or is likely to affect the distribution of alpine plants. McGlone cited two other studies, one on alpine grasshoppers (White and Sedcole 1991) and one on an alpine cockroach (Sinclair 2001) both of which

indicated negative impacts for these insects of alpine warming.[6] A modelling exercise by Halloy and Mark (2003) gave pessimistic results about climate change impacts on alpine plant diversity in New Zealand. Their study assumed a temperature rise of 3^0C over the next 100 years and factored in a probable response of existing exotic species in the alpine zone along with indigenous species. The model projections indicated a potential loss of 200-300 indigenous alpine species and significant increases in the number of exotic species. Over millennia, ongoing fragmentation of alpine areas could favour speciation, but in the short term they predicted the loss of about 80% of existing alpine islands and increases in extinction risks.

Continuous winter snow cover protects some alpine plants by reducing the number of freeze-thaw episodes they would otherwise experience. Experiments have shown that species normally protected by snowbanks or sheltered areas (such as *Celmisia haastii* and *C. prorepens*) are less frost resistant than plants from exposed habitats (e.g. *C.viscosa, Poa colensoi*) (Bannister *et al* 2005). Long-term prediction of the effect of these impacts is difficult, however, because while warmer temperatures might lower frost resistance, they would also reduce the number of frosts.

Potential problems for alpine invertebrate species may follow from the evidence that warmer temperatures increase mast flowering in alpine grasses (Webb and Kelly 1993; McKone *et al* 1998). An abundance of seed is likely to increase house mice (*Mus musculus*) numbers and, consequently, stoat (*Mustela erminea*) numbers. Both species also increase after heavy seedfall in nearby montane beech forest. In both habitats mouse diet is dominated by invertebrates, especially weta, spiders, caterpillars and grasshoppers (Wilson *et al* 2006). Wilson and colleagues found that high mouse numbers were associated with low weta numbers, suggesting mouse predation reduces weta abundance. More frequent mast years may therefore increase predation of indigenous invertebrates, such as weta, as well as of rock wrens (*Xenicus gilviventris*) which have been declining in abundance and are classified as a nationally vulnerable species (Hitchmough 2002). What is not known is how warmer alpine conditions will influence growth and survival rates of invertebrates. It could be that their survival rates would improve and reduce the negative impacts of increased predation.

5. Interactions with ecological processes

5.1 Predation and diseases

Habitat loss and hunting for food were major factors in the decline and extinction of a number of indigenous species during the early Maori and European settlement periods. The major process now responsible for reducing populations of invertebrates, reptiles, amphibians and birds is predation by introduced predators (Clout and Lowe 2001). As

[6] We should not draw too many inferences from Northern Hemisphere studies on the responses of insects to low temperatures as these can be quite different from those in the Southern Hemisphere (Sinclair et al 2003). Responses to freeze-thaw changes are an important aspect of climate change response by insects.

McGlone (2001) points out the mammalian predators, responsible for the most noticeable predations impacts, are likely to show little direct effects of increased temperature relative to food supply. The most serious predators (rats, stoats, possums) are already distributed throughout the country and will show few benefits from temperature rises. Improved winter conditions (drier and warmer) may benefit survival rates of juvenile rodents and possums which would mean quicker recovery from control operations (Hay 1990).[7] How much those same improved winter conditions might also improve the survival of species threatened by these predators is not known.

The link between climate change and increased seedfall (masting) of beech species and alpine grasses has been discussed in Section 4.4 as well as the associated links to higher numbers of rats, mice and stoats. The extent to which masting years and the subsequent increases in rodent and stoat numbers have negative effects on bird populations has been the subject of much research. Birds are eaten by stoats in all years, regardless of seedling levels (King 1983) and the proportion of birds in the diet of stoats was similar in mast years and non-mast years (Murphy and Dowding 1995). The abundance of food can also increase bird densities (via increased invertebrate densities) which may contribute to the higher stoat productivity in the year following a beech seedfall. These relationships are complex and the long-term impacts of more frequent seedfall on indigenous species are difficult to predict. What is clear is the ongoing risks of extinction of yellowhead/mohua (*Mohoua ochrocephala*) populations from predation in beech forests, regardless of climate change.

Invertebrate species are much more influenced by climatic conditions than mammals. The social and paper wasps are the major introduced invertebrate predators that presently affect New Zealand's biodiversity. The two species of *Vespula* wasps, now well established in beech forest communities, have an estimated biomass in honeydew beech forests that can be as great as, or greater than the combined biomasses of birds, rodents and stoats (Thomas et al 1990). Wasps compete for sugar resources with nectar-feeding birds and insects, are major predators of invertebrates and compete for invertebrate prey species (notably caterpillars) that are normally important food for insectivorous birds. Wasps can reduce the standing crop of honeydew drops by over 92% for 5 months (Moller *et al* 1991) and it has been suggested that since wasps established here in 1945 the invertebrate taxa that are most vulnerable to wasp predation have already been removed (Toft and Rees 1998). Beggs (2001) found that wasps are negatively affected by wet winters whereas warm, dry conditions (which are likely under climate change conditions for large parts of the wasps' range) can lead to explosive population growth.

In addition to wasps, there are introduced ant species that are likely to benefit from warmer climatic conditions. Invasive ants have been called "*an ecologically destructive phenomenon affecting both continental and island ecosystems throughout the world*" (Holway 2002). Invasive ants not only out-compete native ant species, they also prey on a wide range of invertebrates as well as vertebrates and can disrupt mutualisms between

[7] In fact, most mammalian species tend to have better survival rates under conditions of milder, drier winters compared with cold, wet winters (King 1990), hence the main pest herbivores (goats, possums, deer, rabbits, hares) should also do better under milder winter conditions, all other factors aside.

plants and insects. New Zealand lacks a large, indigenous ant fauna. Exotic ants therefore face little competition from other ants and find it easy to establish in the mild, climatic conditions. Without past selection pressure to adapt to aggressive ant species, New Zealand's large, flightless, ground-dwelling insects (such as weta) may be particularly vulnerable to new invasive ant species and the ongoing spread of those ant species that are already here (Moller 1996).

Two major pest ants are already established in the warmer northern regions of New Zealand – the big-headed ant (*Pheidole megacephla*) and the Argentine Ant (*Linepithema humile*). The Argentine ant is a major pest of Mediterranean-type ecosystems worldwide and can greatly increase the abundance of its worker ants in conjunction with El Niño events (DiGirolamo and Fox 2006). The Argentine ant was discovered in Auckland in 1990 and now occurs in other northern urban centres (Ward *et al* 2005). Argentine ants have been found up to 20 m inside forest habitats and up to 60 m inside scrub habitats (Ward and Harris 2005). Argentine ants therefore seem unlikely to be a threat within intact indigenous forests; at least so far. By contrast, in open habitats and highly fragmented landscapes, where many threatened indigenous species are located, their impacts could be significant as they spread and establish new colonies beyond urban areas. Like other invasive ants the Argentine ant has the capacity to out-compete indigenous invertebrate species and dominate the biomass, just as wasps have done in beech forests. Warmer, drier conditions will favour the continuing dispersal of Argentine ant into regions south of Auckland.

The world's worst invasive ant, the red imported fire ant (*Solenopsis invicta*), has established nests in New Zealand on three separate occasions in the past 5 years.[8] Modelling work suggests that warming conditions will significantly increase the expansion of *S. invicta* into the north-eastern USA (Morrison et al 2005), since it is limited only by cold or dry conditions. The likelihood that the red imported fire ant will establish in New Zealand, with devastating consequences for native invertebrates, reptiles, frogs and ground-nesting birds, will continue to rise with increasing trade and the global spread of the species. It has established in Malaysia, Taiwan and Brisbane[9] in only the past several years. Eradication efforts are continuing in Brisbane; if eradication fails, however, and there was no control, *S. invicta* could invade over half of Australia within 35 years (Scanlan and Vanderwoude 2006). One hopes that the red imported fire ant is contained and eradicated within the boundaries of Brisbane's suburbs, given the extent of trans-Tasman trade and the ease with which this species can 'hitch-hike' on human movements of goods. Other species of fire ant are also potential invaders.

In 1990, MAF Technology undertook a review of the impact of climate change on pests, weeds and diseases with a focus on northern New Zealand, expecting this region would

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[8] Single nests were found and destroyed at Auckland International Airport in 2001 and the port of Napier in 2004. A third large nest was discovered and destroyed at Whirinaki, near Napier, in June 2006. Surveillance over the surrounding area was scheduled to continue through the summer of 2006/07.

[9] The red imported fire ant was discovered in Brisbane in 2001 at two separate locations. Eradication efforts have been underway since then at a cost of over A$140 million. The potential economic burden is also a major concern. The Australian Bureau of Agricultural and Resource Economics has predicted a cost to Australia of $8.9 billion over 30 years, if the ant is not controlled.

be the first affected by temperature and rainfall changes (Prestidge and Pottinger 1990). While the focus was on agricultural and horticultural impacts some of their findings have wider relevance for other systems. Invertebrate pests currently restricted by climate to the warmer northern regions, including cattle tick and blowflies, would extend into the South Island with pest outbreaks likely. They noted that many pests and diseases have been carried to New Zealand on westerly airstreams, such as cutworms, tropical armyworms and various leaf rust diseases. These westerly airflows are predicted to increase in strength under warming climate scenarios and thus increase the likelihood of further airborne exotics arriving unannounced. Such arrivals will not be picked up by the usual border and port surveillance systems and will require a much wider surveillance effort if early detections are to be made of unwanted, airborne arrivals.

A 3^0C temperature rise would make many areas of coastal New Zealand suitable for the establishment of the Mediterranean fruit fly and Queensland fruit fly. New Zealand would also be at greater risk to the establishment of insect vectors of animal and human diseases, such as *Anopheles* mosquitoes and biting midges of the genus *Culicoides*. Warmer temperatures accelerate insect life-cycles and are already extending the ranges of malaria-carrying mosquitoes into regions that previously were too cool for their survival.

While the *Anopheles* mosquitoes that carry human malaria are absent from New Zealand the mosquito vector for avian malaria (*Culex quinquefasciatus*) has been here for over a century. Unlike the situation in Hawaii, where avian malaria contributed to the extinction of many bird species in the 1920's and 1930's, its impacts in New Zealand have been less severe to date. However, over the past three decades, the mosquito vector of avian malaria has been spreading throughout New Zealand. This raises the possibility that, as climate change and land use continue to alter mosquito distributions, much of New Zealand's native avifauna may be at risk (NZ Fourth National Communication 2006).

Another potentially important virus for New Zealand animal species that is also spread by mosquitoes is the West Nile virus. It was first isolated from a human in the West Nile province of Uganda in 1937. The virus then spread through Africa, Europe in the 1960's, then Asia and, in 1999, into North America. Initially, it had little impact on wildlife there, but has since proven to be particularly virulent. In the few intervening years, West Nile virus has killed mammals (including over 500 people), reptiles and tens of thousands of birds in North America from 225 species in 55 families.[10] Birds that carry the virus can survive the infection and then act as the principal hosts. Two invasive mosquitoes (*Aedes albopictus* and *Ochlerotatus japonicus)* are highly susceptible to West Nile virus infection and can transmit the virus by biting. Both species are often intercepted at New Zealand ports and airports, but have not yet established in New Zealand. Should they do so, climatic conditions would favour their widespread distribution throughout the country. The consequences could be severe for already threatened bird species, but how different species would react to this particular virus requires further study.

[10] http://www.landcareresearch.co.nz/research/biosecurity/stowaways/mosquitoes/mosquitoes_disease.asp

5.2 Migratory bird species

Many species of wading birds migrate to New Zealand for over-wintering from their breeding grounds in the vast tundra expanses of Siberia, Eurasia and Alaska. The two most common summer visitors to our northern coastal estuaries and Farewell Spit are the bar-tailed godwit or kuaka (*Limosa lapponica*) and the lesser (or red) knot or huahou (*Calidris canutus*). A study of how climate change may affect migratory species (Robinson *et al* 2005) identified a number of stresses from climate change that could reduce numbers of these and other migrant birds to our shores. These extraordinarily long annual migrations push individuals to their physiological limits; any perturbations are likely to have adverse consequences. Successful migrations rely on the rapid build up of energy reserves, good weather conditions, key stopover locations and winter feeding habitats. As most waders are estuarine feeders, rises in sea levels with losses of food species, either in northern or southern locations, could have adverse effects depending on how prey species respond to habitat changes. The predicted changes in wind patterns and increases in storm frequency might affect the ability of birds to complete journeys.

Climate induced changes in habitat are predicted to be greatest in the Arctic; how this will affect different species is not yet clear. There are complex changes already occurring with changes in the timing of migration for some migrant species and changes in the peak timing in abundance of prey in response to warmer temperatures. Some important stopover areas are being threatened, not by climate change, but by loss of key wetlands and estuaries to development projects, notably along the Asian flyways. With so many factors influencing the survival of migrating species, in such widely separate regions, any predictions of how climate change will affect these species are currently problematic, according to Robinson *et al* (2005).

5.3 Weeds

Aquatic and terrestrial ecosystems are affected to varying degrees by a variety of exotic plants, nearly all of which were deliberately introduced to New Zealand for ornamental or agricultural uses. (See also Section 4.2.) Over 20,000 exotic plant species have now been introduced to New Zealand and 2,000+ of these species have now ‘naturalised’, i.e. they have established self-supporting wild populations. This is roughly the same number of species of vascular plants that are indigenous to the country. Over 10% (about 250) of the naturalised exotics have increased to the extent that they are now regarded as weeds in urban, rural or natural habitats where they cause significant ecological or economic damage. The process of conversion from ornamental, to naturalised self-sustaining populations, to weed status is ongoing[11] and is likely to become faster under conditions of warmer temperatures and more frequent extreme events. Warmer temperatures will favour range expansion of the many sub-tropical ornamentals now growing in Auckland and other northern areas. These parts of the country already have very high numbers of

[11] Exotic plants are currently naturalising at the rate of 1-3 per year.

weed species which have adverse impacts on native ecosystems, especially on the fragmented forest remnants that are common throughout Northland.

Extreme events, such as storms, droughts, heavy snowfalls and erosion create open disturbed conditions that favour light-demanding fast growing plants – a characteristic of many weed species – that can most rapidly take advantage of the reduced competition for light, space and nutrients. In a study on how deer control options can affect the dynamics of mountain beech forests in Kaweka Forest Park, Duncan *et al* (2006) commented that disturbed areas in mountain beech forest often contain exotic, light-demanding weedy plants. When deer numbers are sufficiently high to delay forest recovery the weedy species present can persist longer and produce more seeds. How high weed numbers might affect long-term forest dynamics and the restoration of forest canopy is not clear, but it adds another negative factor to the process, along with herbivore pressures and an expected increase in extreme events.

Pasture weeds currently restricted to the northern North Island may extend southwards with warmer weather[12] (Prestidge and Pottinger 1990). Good growing conditions that maintain strong, competitive pasture serve to inhibit weeds, whereas stressed pastures favour weed growth. Hence less summer rainfall and more frequent droughts will lead to more open pastures and an expansion of problem weeds such as ragwort and nodding thistle. Many agricultural weeds, along with other naturalised exotic species, can also have serious impacts on native flora and fauna (Williams 1997). When considering the future interactions between climate change and the further spread of weed species it is important to recognise that: "*Many exotic fleshy-fruited plants have yet to naturalise in New Zealand and very few naturalised species have reached their potential range at even a provincial scale*." (Williams and Cameron 2006). Weed problems are therefore likely to get significantly worse with unpredictable, disruptive impacts on indigenous ecosystems. In this context the role of introduced birds, such as the blackbird, in spreading exotic weeds could make the situation worse for indigenous species (see next section).

5.4 Pollinators and seed dispersers

New Zealand plants have relatively few specialised pollinators and few, if any, that are exclusively pollinated by birds (Clout and Hay 1989). They note that this is in marked contrast to the importance of frugivory (fruit-eating) and seed dispersal of forest species by native birds. About 70% of the woody plants in New Zealand forests have fruits suited for vertebrate dispersal and, of these, most are probably dispersed by birds (Clout and Hay 1989). These intimate and important bird-plant relationships have now been severely disrupted through the recent extinction of many fruit-eating birds (e.g. moa, huia, piopio) and the diminished range or density of many others (e.g. kiwis, kokako, bellbird, tui and weka). Several trees with large-fruited plants now depend almost entirely on the pigeon or kereru *(Hemiphaga novaeseelandiae*) for their dispersal (Clout and Hay 1989). They regarded this as a 'precarious situation' especially as predation continues to reduce kereru

[12] Two prime candidates are the pasture weeds –*Paspalum dilatatum* and kikuyu grass (*Pennisetum clandestinum*).

numbers in various places. "[*Kereru] are arguably the most important seed-dispersing birds in New Zealand forests, because of their catholic diet, their mobility, and their widespread distribution*." McGlone (2001) considered that the loss of seed dispersers will interact with climate change mostly by reducing the ability of bird-dispersed trees and shrubs to keep up with their preferred climate space.

Exotic birds can play positive as well as potentially negative roles in seed dispersal. In preliminary work on the role of the blackbird in assisting weed invasions Williams (2006) noted that the naturalised European blackbird (*Turdus merula*) is the most widely distributed, seed-dispersing bird in New Zealand. Where there are intact tracts of indigenous vegetation blackbirds contribute positively to the dispersal of fleshy fruits of early succession species. In highly modified landscapes, as in the eastern South Island, extensive new plant communities are developing that are dominated by naturalised fleshy-fruited species.[13] Their fruits are of major importance to introduced birds and blackbirds may well be the most important disperser of their seeds, although more study is warranted (Williams 2006). These communities of naturalised plants, including weed species, are expanding (Williams and Cameron 2006) and are likely to benefit from the potential stresses and disruptions to native plant communities and ecosystems that would follow from more extreme events, such as droughts and fires (see next section for potential impacts on eastern beech forests). So while the bird-dispersed native trees and shrubs may find it hard to keep up with climate change demands, the new communities of shrubby weeds may continue to expand, thanks to the European blackbird.

5.5 Fire impacts

Although there have been major fire episodes in New Zealand's geologically recent past (see Prologue), native ecosystems evolved in an environment when fires occurred infrequently and therefore few indigenous plants are well adapted to tolerate or resist fire (Ogden *et al* 1998). Almost half of the remaining area of indigenous forest in New Zealand (about 2.9 million ha) is dominated by beech (*Nothofagus*) species (Wardle 1984). These extensive forests are home to many indigenous species and play important economic roles in soil protection and for recreation. Beech species are, however, poorly adapted to fire and even low temperature burns can destroy forests (Wardle 1984). Where fire has destroyed beech forests, particularly in the drier eastern regions, regeneration can be very slow as beech seed is produced infrequently and is not adapted for long distance dispersal (Allen and Platt 1990).[14] Efforts to artificially restore beech forest after fire found that the 'window' for doing so was less than 2 years before competition from pasture species inhibited the establishment of native species (Ledgard and Davis 2004). Even then obtaining the necessary quantities of beech seed would make such re-seeding efforts problematic for large areas.

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[13] Including weedy shrubs such as Darwin's barberry, elderberry and hawthorn.
[14] Warming conditions, on the other hand, are stimulating more frequent seeding years by beech (Section 4.4).

Climate change predictions for New Zealand associated with the Southern Oscillation are likely to increase the frequency and severity of fires especially in the east (McGlone 2001). If the Southern Oscillation fluctuations intensify as predicted, McGlone anticipated a major effect will be on scrub grassland and regenerating forest communities in drier districts close to roads and settlements, where fires are most likely to start. *"Among the results could be retreat of beech forest east of the main divide, loss of native species in grassland/shrubland, and proliferation of annual exotic grasses."*

5.6 Human-induced fragmentation

There have been a number of references in previous sections to the impacts and stresses on fragments of native vegetation. Forest removal, intensive land use, fire and the draining of wetlands throughout New Zealand have reduced many previously intact and extensive areas of vegetation to much smaller and vulnerable fragments. These fragments lose species at faster rates than large areas of intact vegetation and are more susceptible to invasions by weeds and pests, especially when they are close to towns and human use (Timmins and Williams 1991). Humans, not climate change, continue to be the major driver for the spread of weeds from gardens to natural sites. Fragmentation has been a particularly severe problem in lowland forests and wetland communities, caused by clearance and draining. The result has been patches of modified indigenous ecosystems, surrounded by extensive agricultural areas, "*…saturated with predators, herbivores, weeds and pests, and regularly sprayed with herbicides and toxins*." (McGlone 2001). Many of these areas are also important habitats that are sheltering threatened plants and animals, albeit somewhat tenuously, given the lack of legal protection that applies to many of these places (Walker *et al* 2006). Quite apart from ongoing loss through human intervention, these native fragments lose species more quickly because they are more vulnerable to extreme events such as storm damage, flooding, frost, extreme drought, as well as increased openness to new weeds and pests.

Climate change is likely to increase the intensity and frequency of most of these negative effects, argues McGlone (2001). These extreme events are more devastating for small patches of habitat, compared to larger, unbroken stretches of indigenous ecosystems. Fragments are also likely to be further away from the source of new species to replace those that are lost from local plant/animal communities. Improving the chances that these important fragments will survive the current and additional stresses they will face may therefore depend in large part on the ability of native birds to fulfill their role as seed dispersers (Section 5.4). In this context it is important to have a better understanding of the role that wildlife corridors could play in supporting natural processes of regenerating native plant communities (Section 3.3). Even if wildlife corridors were established, the loss of native birds and reduced numbers of kereru may mean that corridors are not enough to sustain these natural processes (John Leathwick, pers. comm. 2006).

6. What don't we know

6.1 Responses of complex non-linear systems

The first direct effects of rising levels of greenhouse gases are rising air temperatures and increasing ocean acidity – the *first order* changes. These are the easiest changes to predict and anticipate despite the complexities and uncertainties associated with climate models. The *second order* changes includes responses such as rising sea levels, changes in the patterns of ocean currents, and meltdown of glaciers and polar ice. These involve another level of complex physical and hydrological systems that also include degrees of uncertainty and ignorance about processes. For example, there has recently been a major re-think about the process by which glaciers, such as the massive Greenland glaciers, melt with rising temperatures. Rather than being a slow and gradual process, as was previously thought, new studies have shown that the movement of surface water down crevasses can lubricate the join between the bottom of the glacier's ice and the underlying bedrock. The result is a much more rapid movement of ice sheets towards the ocean and more rapid melting. "*These flows completely change our understanding of the dynamics of ice sheet destruction*" [said climate scientist Richard Alley]. "*Even five years ago, we didn't know this.*" (The Guardian, 30 August 2006)

The *third order* changes of climate change are the most complex, are more unpredictable, and have greater uncertainties associated with them. They also have the capacity to impact directly on our economic and environmental well-being and directly affect efforts to achieve sustainable development.[15] They include changes to the composition and condition of marine, terrestrial and freshwater ecosystems, impacts on agricultural systems, and the consequences for human health and human settlements. Changes in these systems are generally non-linear, characterised by sudden changes into different states that can be long-lasting or permanent. Examples of non-linear systems are the slow build-up of nutrients in the Rotorua lakes finally leading to rapid declines in water quality and increases in aquatic weeds, or the ecosystem changes caused by the arrival of exotic species, such as the diatom (*Didymosphenia geminata*) in Southland rivers and its rapid spread throughout South Island rivers since October 2004.

Climate change will promote further unexpected ecological responses in addition to those that have already occured. Some will be at the level of whole ecosystems; others will be caused by disruptive impacts of particular species. The latter are more likely to be caused by invertebrates, as in the case of the mountain pine beetle (Section 4.3), than by vertebrates. Problems from current and new weed species should be included as significant change agents. The broad climatic conditions within which ecological responses will occur have been identified (Section 2); what is much less predictable is what changes are likely, where, when and their implications.

[15] Issues around complexities, uncertainties, science and their research and policy implications are explored in detail in a PCE report (PCE 2004a).

6.2 Policy and research responses

What has been done to understand and anticipate potential threats to New Zealand's biodiversity? Over the past decade, there has been little policy work or research specifically considering the impacts of climate change on New Zealand's indigenous biodiversity. The topic is absent in the New Zealand Biodiversity Strategy (Section 1.1) and it features only recently in funding by the Foundation for Research Science and Technology (FRST) under the 'Global Processes' portfolio. One programme funded under this portfolio is looking at the past and present responses of different ecosystems to fire. There do not appear to be research programmes investigating climate change impacts specifically focused on New Zealand's marine ecosystems, despite overseas evidence that such effects are already occurring (Section 4.1).

The Government's climate change work programmes (MfE 2006), released in June 2006, include an adaptation programme (Programme 15). It refers to the need "…to recognise the breadth of work required to help New Zealand prepare for and adapt to the impacts of climate change *in the long term (30-40 years)*." (emphasis added, page 89) It also refers to building on existing initiatives rather than developing new science. This concept of "long term" bears little resemblance to the time scales over which significant ecological changes are likely to occur, as discussed in Section 3. The only reference in that programme related to biodiversity is that the adaptation work 'should consider' pest management. On 13 September 2006, the Cabinet Policy Committee (POL Min (06) 20/12) agreed that the climate change impacts and adaptation work programme should have an immediate focus on: water and coastal; infrastructure investment and maintenance; primary industry; biodiversity and biosecurity. It is not yet clear how this directive will translate into specific work programmes or whether there will be any focused research examining climate change impacts on key ecological processes.

McGlone (2001) proposed that climate change effects on biodiversity would be greater over intermediate and long-term time scales, rather than in the near future.[16] He identified three larger climate change issues over major time and spatial scales:

- the future of long-term evolutionary processes in a warming, human-dominated world;
- restoration options for ecosystem properties over large areas of landscape;
- long-term outcomes of indigenous-exotic species interactions.

Although these are not the issues that exercise day-to-day policy decisions (Section 3.3) today's choices will strongly influence the distant-future, therefore they should be discussed now. So far, the policy focus has been on short-term biodiversity maintenance. It is 5 years since McGlone raised his concerns; the discussion has yet to begin. When the discussion does occur it will need to start with an examination of the most appropriate framework within which the climate change policies for biodiversity should be assessed. What that framework might look like will be considered in the next section.

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[16] The exception could be an early rise in the impacts of new or current pests – see Section 7.

McGlone (2001) listed five areas as warranting discussion and policy development:

- Indigenous biota range expansion within New Zealand.
- Conservation of climatically threatened species.
- Ecosystem processes and evolutionary change.
- The role and status of exotic species.
- Integration of biodiversity issues into Kyoto-related mitigation strategies.

McFadgen (2002) reported on implications of climate change for Department of Conservation activities. He emphasised the significance that more frequent extreme events would have for the Department's operations. McFadgen also stressed the need to develop research projects that involve long-term monitoring studies to detect effects of climate on conservation. I would add that this research should be incorporated into other national monitoring initiatives which are now well overdue, despite their wider relevance and importance for policy, effective conservation management and sustainable development (Green and Clarkson 2005).

There will continue to be 'unpleasant surprises' from the effects of climate change, and they may well arrive courtesy of insects. An intelligent policy and research response, with greater investment than has occurred so far, should reduce the amount of 'surprise' and increase the chances that adaptive responses are relevant and effective. Failure to do so has wider implications for the sustainable development options for New Zealand.

6.3 A framework for policy and management responses

Policy and management agencies such as the Department of Conservation and regional councils face two particular challenges with respect to how they plan for and respond to climate change effects. First, the knowledge of what those effects are likely to be is poor for most of the ecosystems they are charged with managing. Most agencies with conservation responsibilities also lack monitoring regimes to detect long-term changes (Green and Clarkson 2005). Responses of ecosystems are likely to be complex and, while certain responses can be anticipated, other responses will be unpredictable. Without a better understanding of the major changes that are likely over large scales of time and place, forward planning is more likely to be a hit-and-miss affair.

The second challenge is a reflexive one for management agencies. Current policy and planning frameworks are, for valid historical and pragmatic reasons, focused on relatively short-term time horizons. When climate change shifts whole systems to very different states, which will be well outside any 'management' to control or influence, there is a need to re-think objectives differently both in terms of timeframes and spatial dimensions. For example, Keeney and McDaniels (2001) proposed a framework to guide thinking on climate change policies. They outlined an 'adaptive framework' which responds to the inherent difficulties of accurately forecasting long-term changes by building in a deliberate 'learning over time' structure and approach. It involves using concrete objectives for near-term policies and proxy objectives for addressing long-term climate change problems.

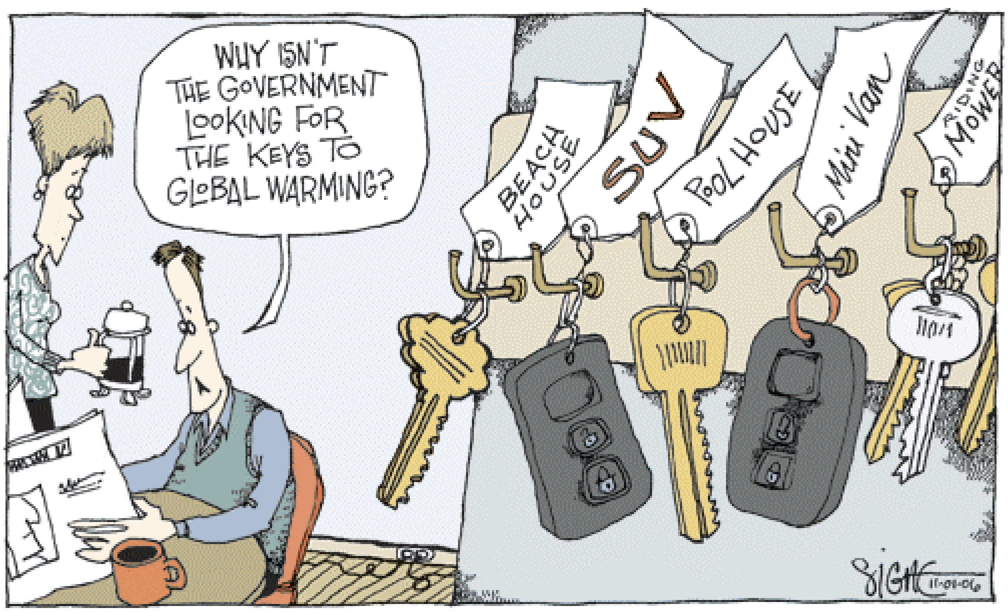
There are links in this approach to the current practices followed (or attempted) in adaptive management options to managing biodiversity. Despite the demonstrated benefits of the adaptive management approach it is not easy to achieve in practice. As Pritchard and Sanderson (2002, p.166) have elaborated, part of the difficulty is how to build a 'non-bureaucratic bureaucracy'. They ask "*Is it possible to have a legitimate, capable, and responsible management organisation that is constantly reforming and reinventing itself?*" That suggests a challenge not only for DOC, but also for regional councils charged with anticipating and managing for environmental changes, over scales of time and space and linkages that were hardly anticipated when the structural and legal mandates of these agencies were established.

Since these agencies also operate within particular social and political systems it will be important to factor in these elements, including private sector interests, when developing a response to the challenges of both short- and very long-term planning and policies.

7. Conclusions

"*We need to discover how the world works to know better our place in it.*"
Wes Jackson, 'Alters of Unhewn Stone' 1987.

Wes Jackson was writing at a time when the full implications of climate change were a distant smudge on the policy and political horizons. His exhortation is more important now given our current understandings of the potentially profound transformations that climate change could have on the natural world and, in turn, on our social, political and economic futures. In a perverse way those understandings expose the limits of our current knowledge of how key ecological processes are likely to be affected, over what timeframes, and what intelligent policy responses might look like. If "knowing our place" means understanding how to live wisely within the limits of natural capital, then we still have much to learn and apply.



The key causes of global warming are now widely understood from a scientific perspective. The progress that we now need to make concerns the necessary responses, both on mitigation and adaptation options. A central element of adaptation responses will be a better understanding, despite the inherent uncertainties, of the linkages between climate change and our indigenous biodiversity. In reviewing the relevant literature this paper has shown that the effects of climate change will be felt widely, from marine to alpine environments, and across a range of key ecological processes. I have highlighted climate change effects on predation, spread of diseases and seed dispersal, as well as weed and fire impacts. *Many of these are pre-existing threats, particularly pests and weeds; climate change will make their impacts more pervasive and management options more difficult to devise and implement*. I also point out the extremely limited amount of research that has been commissioned to date to better understand these changes and thereby help to make the management options clearer and more effective.

Some of the effects of climate change may be happening already, such as more frequent beech seeding events, while landscape changes to the distribution patterns of some forest species will take hundreds of years to appear. Rather than small annual temperature rises, it will be the associated increases in the frequency and severity of extreme events (heavy rainfall, droughts, very hot days, stronger winds) that will cause significant impacts for biodiversity. Our landscapes have long been patterned by the outcomes of extreme events – forests flattened by wind storms, erosion after heavy rains, altered plant communities following prolonged droughts. The massive weather patterns generated by the Southern Oscillation are also likely to see its extreme conditions – El Niño and La Niña – become more intense under future climate conditions. New Zealand is already characterised by wide variability in daily weather and seasonal climates. Not only is New Zealand a dynamic country geologically speaking, it also has a dynamic climate. In some years our weather seems to be dominated more by 'events' than by the seasons.

In pre-human times, New Zealand's unique ecosystems and species had the resilience to bounce back from the environmental and climatic shocks they experienced. The extensive wetland systems, forests and grasslands that stretched unbroken from coasts to mountains had all the component species, particularly the birds, to spread the seeds and regenerate what had been lost. Currently, some ecosystems are so diminished and fragmented that the natural processes of recovery may be inadequate or too slow to achieve restoration before exotic species or another extreme weather event intervenes.

Another class of changes that will occur in the longer-term future will be the shifts in the altitudinal and latitudinal ranges of species. There will be major movements of species and communities southwards and upwards as temperatures rise and new regions become habitable for warmth-demanding species. Another important class of changes is long-term changes in nutrient cycling and changes in productivity within ecosystems. Freshwater ecosystems, already diminished from a range of human-induced pressures, will face further disruptions from the more frequent droughts that will reduce water flows in streams and rivers and improve conditions for pests and aquatic weeds.

In summary, the most serious problems, and the first to become apparent, are likely to flow from the climate change interactions with the current threats caused primarily by pests and weeds. These include: the establishment of new pests (esp. insects) and weeds; southwards expansion of existing weeds and pests (esp. insects); extreme weather events, especially droughts, favouring the establishment of exotic plants and weeds in place of native species in the recovery phase; damage to habitat fragments by pests and weeds, in addition to their greater vulnerability to extreme weather events.

Management agencies have specific climate change challenges. They need to start planning now for more intense impacts from pests and weeds. More thought needs to be given to the really long-term consequences of climate change and how best to keep future options open. This will require serious work on the role and value of wildlife corridors. These issues have major implications for private land owners as well.

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